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Title: UNR ETI Computational Investigation (Year 2):

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The LANL ASC Arbitrary Lagrange/Eulerian (ALE) code, FLAG [1], is being used to model experiments conducted under this grant in order to understand the physics limiting high-current conduction and thermal plasma production. This includes the effects of nonlinear magnetic diffusion (NLMD), the magnetic Rayleigh-Taylor (MRT) instability, and the electro-thermal instability (ETI).

FLAG is a multi-dimensional, unstructured-grid, multi-material, multi-temperature, shock-physics code with a single-fluid, resistive magnetohydrodynamics (MHD) package. Equations-of-state (EOS), conductivity, material-strength, and melt can be treated with a variety of analytic or tabular models.

Since the experimental target rods are electrically thicker than a skin depth on the time scale of the current rise time, they are thought to be subject to NLMD due to the temperature dependence of the resistivity. The NLMD wave [2] with prescribed applied field, $h(t) \sim h_0(t/\tau)^{1/2}$, and resistivity model $\alpha(T) = \alpha_0(T/T_0)$ was chosen as representative of the conditions expected in experiments. Material motion is frozen so that only the resistive diffusion solver is exercised. The calculated, dimensionless results of magnetic field, current density, and resistivity on a uniform mesh with $N_x = 500$ are shown in Figure 1. At, $t = 10^2\tau$, the NLMD wave has propagated inward to $\zeta_x = 0.5$ where the current density peaks. Under simple, uniform mesh refinement, preliminary results show that the magnetic field solution is at least first-order convergent for this problem.

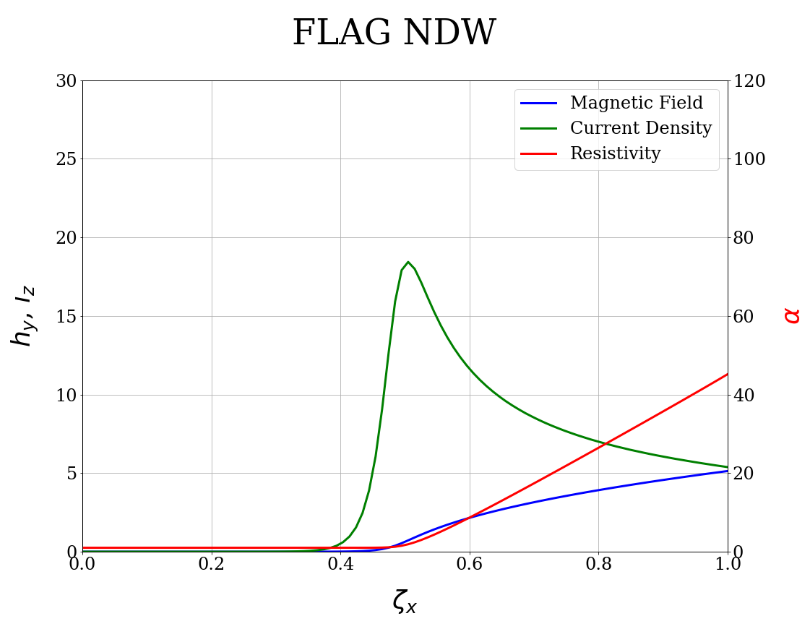

Figure 1. Calculated magnetic field, current density, and resistivity of a NLMD wave.

The initial expansion of the resistively heated target rods has been accurately measured with PDV (53 μm spot size, 1550 nm wavelength) while the load current pulse *($t_{peak} \sim 175$ ns, $I_{peak} \sim 870$ kA)* has been measured with induction coils. This current pulse is used directly to prescribe the magnetic field boundary condition for calculations. Here, FLAG was utilized with cylindrical 1D geometry in a pure Lagrangian mode. The mesh resolution was 0.1 μm. To close the system, the Sesame aluminum EOS table, 3720, was used. A Steinburg-Guinan material strength model was used in conjunction with a tabular melt curve (Sesame 33720). Finally, the recently developed LANL Aluminum conductivity table 23715 was used. The velocity of the outside surface of the rod is tracked and compared to the PDV data from experiment.

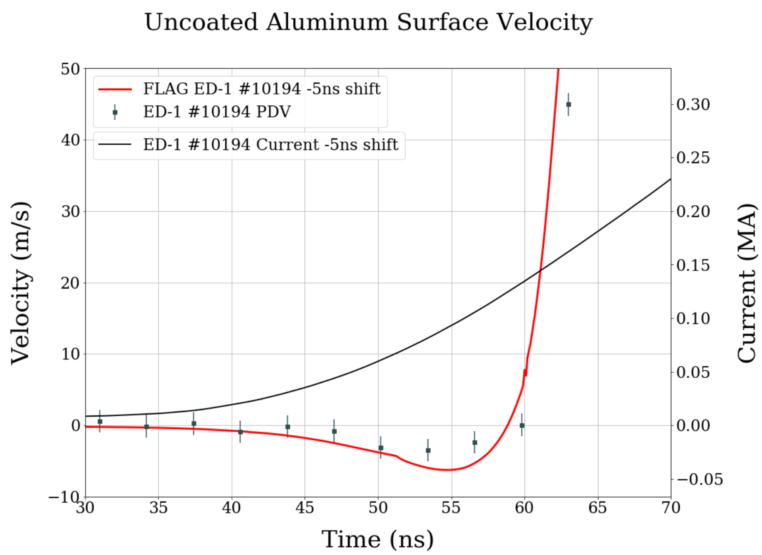

Figure 2. Comparison of FLAG calculation of surface velocity and PDV data of single shot of the ED-1 campaign. Initial expansion due to material melt is shown at t = 60 ns. Material compression due to Lorentz forces is also observed prior to expansion.

Here, a single shot (#10194) of the ED-1 Campaign (Jan. 2020) was used. The target rod consisted of an uncoated, pure (99.999%) aluminum rod with an initial $782\ \mu m$ diameter with a diamond turned finish to reduce surface roughness. The current profile is shown in Figure 2 in black. The first feature for comparison correlates with the melt of target rod and is characterized by initial expansion. Figure 2 shows the measured first expansion at t = 60 ns while the calculation happens at 63 ns. Systematic error in the timing of the PDV diagnostic with respect to the current is ~5 ns (calculation and current were shifted accordingly), so the calculation result is within the uncertainty of the data. Another, surprising, feature is observed prior to melt. Both the data and calculation show a small compression of the material (v < 0) due to Lorentz forces. A velocity of ~8 m/s for 10 ns prior to first expansion is seen.

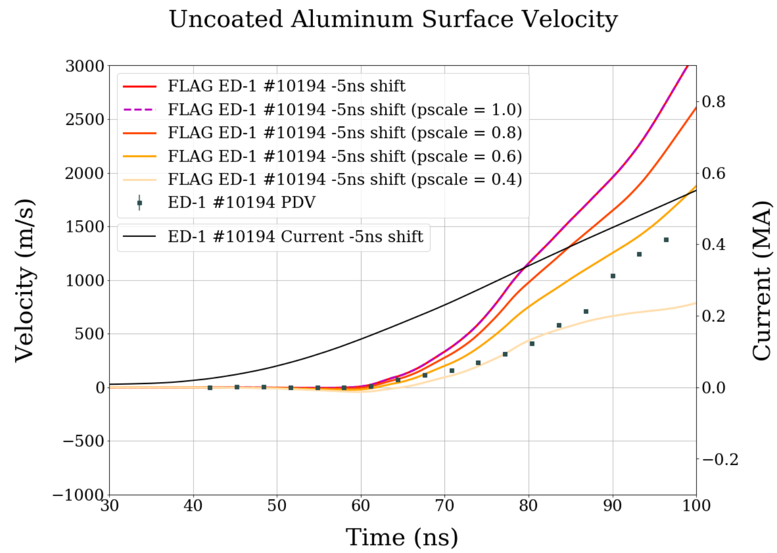

Figure 3 FLAG calculations of EOS with multiplicative scaled pressures (pscale) for LANL conductivity against PDV.

Later in the expansion, the velocimetry data and calculated surface velocity diverge with the calculated velocity larger than the measured. Obvious physical explanations including integrated laser spot-size, material critical density, and uncertainty in the measured current have been ruled out. In order to begin to understand this result, model parameters are varied to quantify their sensitivity. First, the pressure in the EOS is directly scaled by a constant factor showing sensitivity of expansion velocity to EOS pressures. Figure 3 shows that reduction by a factor of 0.5-0.6 in pressure for a given density and specific internal energy is needed for agreement with the data in the range t = 60-85 ns. At later times, however, the calculation shows much better agreement with data in acceleration (6%). One interpretation of this result is that the tabular pressures are too high causing the expansion velocity to be too large in the region of phase space the material resides in during this range. If there is sufficient uncertainty in the table—specifically in this region, these experiments could prove useful as a constraint. In addition, sensitivities to the conductivity and melt tables are also being investigated.

References

[1] D. Burton, "Consistent finite-volume discretization of hydrodynamic conservation laws for unstructured grids.," *LLNL Report UCRL-JC-118788,* 1994.

[2] V. Oreshkin and S. Chaikovsky, "Stability of a nonlinear magnetic diffusion wave," *Physics of Plasmas,* 2012.